



## Computer control in nondestructive testing illustrated by an automatic ultrasonic tube inspection system

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## EIGHTH WORLD CONFERENCE ON NONDESTRUCTIVE TESTING

HUITIEME CONFERENCE MONDIALE  
SUR LES ESSAIS NON DESTRUCTIFS

### COMPUTER CONTROL IN NON DESTRUCTIVE TESTING

Illustrated by an automatic ultrasonic Tube Inspection System

### CONTROLE PAR ORDINATEURS DANS LES ESSAIS NON DESTRUCTIFS

Démonstrée par un système automatique pour l'inspection des tubes par ultrasons.

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**SUMMARY:** In our automatic tube inspection system data (more than half a million per tube) from the ultrasonic dimension measurement and defect inspection are fed into a computer that simultaneously calculates and evaluates the results.

**RESUME :** Dans notre système automatique d'inspection des tubes, les données provenant de la contrôle ultrasonique des dimensions et défauts (plus qu'un demi-million données par tube) sont transmises au ordinateur, qui immédiatement calcule et évalue les résultats.

### 1. GENERAL

In manual inspection the skill of the operator is important for the value of the inspection, but in automatic or semi automatic non destructive examination a direct evaluation of the measuring results is impossible.

Normally paper recording, or an on/off monitor is used to evaluate the results. A faster, safer and better evaluation may however be obtained by the use of a computer.

The computer may be used in the following ways:

- Collect the results and - after some calculation - presenting them as requested. In this case the computer is a data collecting tool, and further evaluation and calculation of the results can be performed afterwards.
- The computer is making the testing and evaluation simultaneously. This has great advantages in automatic production testing where the object is examined to specified tolerance limits. The computer may in this case directly control the inspection and accept or reject the object. However, also by this use of the computer the data may be stored for documentation and/or later evaluation.

We have faced both types of uses in our work. For instance, by non-destructive examination of irradiated fuel pins in the Hot Cells at Research Establishment Risø the results along the fuel pin from  $\gamma$ -scanning, outer diameter measurement and eddy current flaw testing are fed into a computer together with position signals.

Another example is an automatic ultrasonic scanning system for examination of welds with several ultrasonic transducers [Ref. 1.]. This system is under development at the Danish Welding Institute. In this system a micro computer is used during the scanning so the results can be stored on digital magnetic tapes. Evaluation later is done by use of the same computer.

In this paper, however, we have attached the greatest importance to an automatic tube inspection system where a computer is used for simultaneous accumulation and calculation of examination data, as well as evaluation of the results.

<p><b>Title and author(s)</b></p> <p>Computer control in nondestructive testing.          Illustrated by an automatic ultrasonic tube inspection system.</p> <p>by          H. E. Gundtoft and N. Nielsen</p>	<p><b>Date</b> 14.6.76</p> <p><b>Department or group</b></p> <p>Metallurgy</p> <p><b>Group's own registration number(s)</b></p> <p>A-196</p>
<p>8 pages + 1 tables + 7 illustrations</p>	
<p><b>Abstract</b></p> <p>Paper to be presented on 8.9.76 to the Eight World Conference on Nondestructive Testing in Cannes, France.</p> <p>In our automatic tube inspection system data (more than half a million per tube) from the ultrasonic dimension measurement and defect inspection are fed into a computer that simultaneously calculates and evaluates the results.</p>	<p><b>Copies to</b></p> <p>Library (100)</p>
<p>Available on request from the Library of the Danish Atomic Energy Commission (Atomenergikommisionens Bibliotek), Riso, DK-4000 Roskilde, Denmark          Telephone: (03) 35 51 01, ext. 334, telex: 43116</p>	

## COMPUTER CONTROL IN NDT

### II. ULTRASONIC TUBE INSPECTION SYSTEM

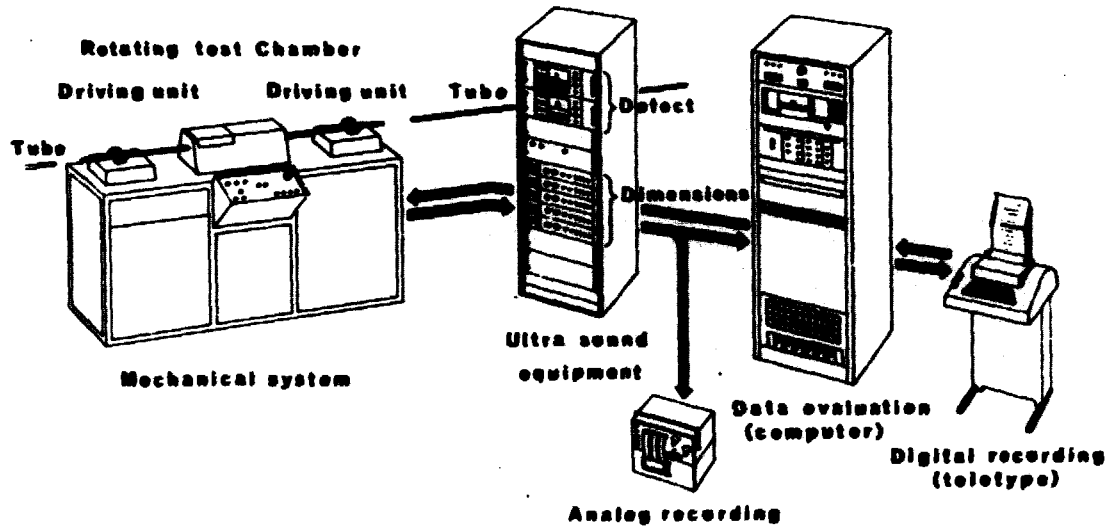


Fig. 1. The main modules in the tube inspection system.

For canning tube inspection close tolerances on dimensions as well as stringent demand on defect size calls for a 100% inspection. Furthermore the amount of tube - up to 200 km for the core in a nuclear power reactor - leads to a compromise between inspection speed, accuracy and economy.

In our system [Ref. 2.] the defect inspection and dimensional measurements are both made by ultrasound using the pulse-echo technique. The total examination is made during one pass of the tube through a rotating chamber with 8 ultrasonic transducers for defect and dimensional inspection. Outer- and inner-diameter as well as wall-thickness are measured. Also ovality and eccentricity can be determined. The defect inspection covers both longitudinal and transverse direction.

On each tube - appr. 4 m long - 500.000 measurements are performed in one minute. The results are visualized on an ultraviolet recorder (Fig. 2.).

For an overall evaluation of one or of a few tubes this is a satisfactory way to present this great number of results. However, evaluation of the extensive data accumulated during examination of a great number of tubes demands the use of a computer.

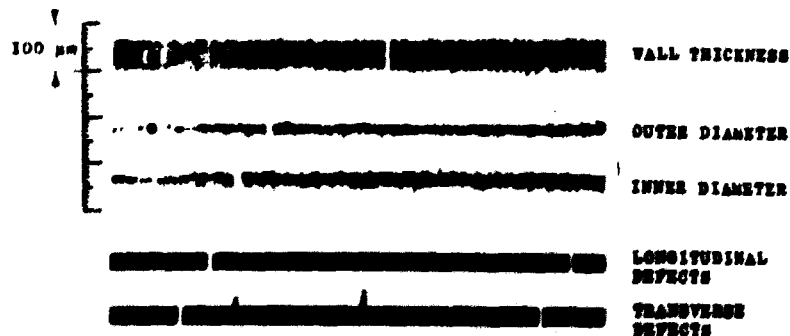


Fig. 2. Analog recording

## COMPUTER CONTROL IN NDT

### III. OUR COMPUTER PROGRAMME

The goal of automatic non-destructive production inspection is to guarantee that every accepted tube does not contain a defect or have dimensions outside the specified values.

Thus the tube must be examined in a pattern which guarantees that a single value outside the tolerance limits will be disclosed.

For canning tube inspection the permissible defect size calls for a very close inspection. Here a compromise must be made between the following test conditions:

- Inspection speed.
- Pulse repetition rate.
- Gated area.
- Effective soundfield in the tube wall.
- The demand of same echo height from defects of same size on the inside and outside surface of the tube.

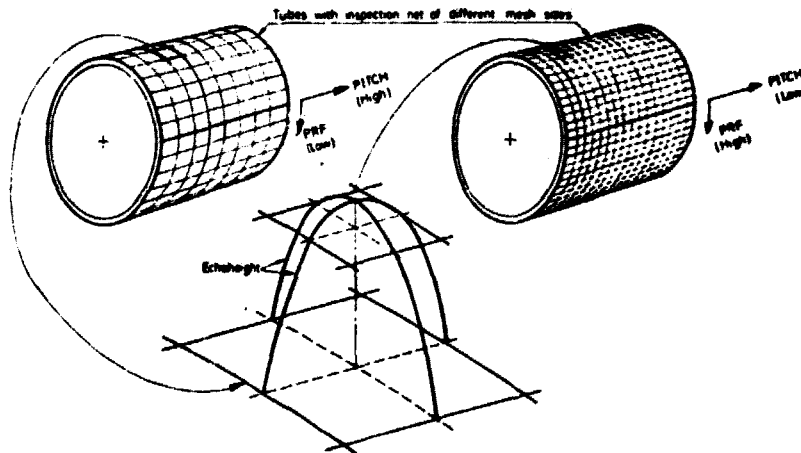


Fig. 3. Echo height variation with relation to "Inspection mesh size".

The inspection pattern forms a net on the tube. The mesh size is determined by the Pulse Repetition Frequency (PRF) along the circumference of the tube and by the pitch in the inspection spiral along the tube axis. The defect echo height will vary with the position of the defect within a single quadrangle in the net (Fig. 3.). The highest accuracy calls for minimum difference between the maximum and minimum value of the defect echo, i.e. small quadrangles. However, a compromise must be made between the inspection mesh size, the capacity and the economy of the inspection procedure.

Our computer programme is able to handle different combinations of above factors, but to describe the system we will use the values which are chosen for our standard inspection:

- Pitch : 2 mm per revolution
- Number of pulses per revolution (fixed) : 24
- Revolution per minute of the water chamber : 3000 RPM
- Linear inspection speed : 6 m tube per minute.

In order to present the results in a way which can be read the individual measuring and examination results are stored in 8 different classes, the limits between which can be chosen freely. Along the tube the results are stored in different sections corresponding to each part of the tube. The smallest part is 1/16 of the total length, but any combination of 1/16 may be shown in the printout.

# COMPUTER CONTROL IN MUT

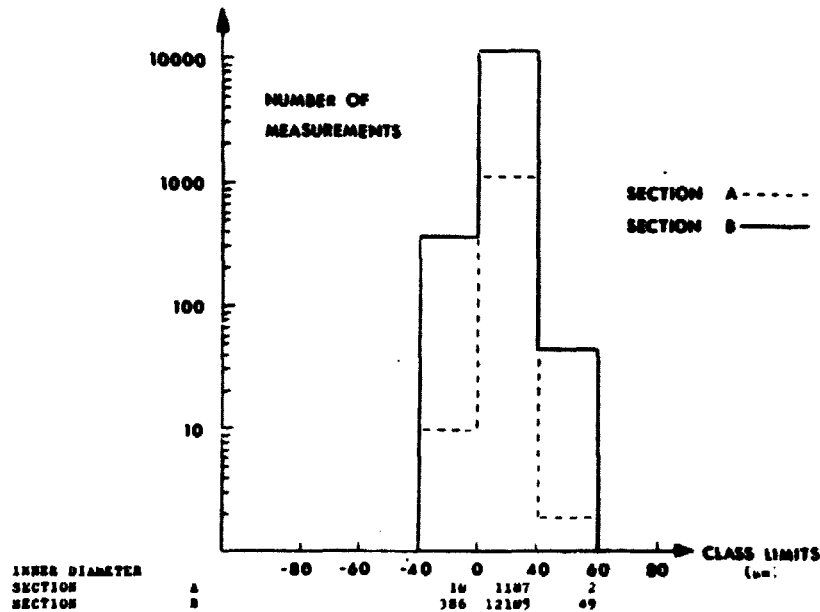


Fig. 4. HISTOGRAMMIC presentation of the examination results for a single parameter.

In this way the results can be presented in a histogram table and the meaning of this is illustrated in fig. 4 for a single parameter. For the whole tube a typical printout is shown in fig. 5.

As the transducers in the rotating water chamber are not in the same axial position the defect signals and dimension values from the same cross section of the tube do not reach the computer simultaneously. However, our programme assures that corresponding values are stored in the same section of the tube. To do this the computer must be programmed with the actual pitch and the section length.

As the fixed values in our standard inspection are programmed into the computer previously, this also assures that each tube is inspected in its full length without any false signals from the connection plugs inserted in the tube ends.

The results for each tube can be retained in different ways, such as printout, punched, put in a disc etc. A direct evaluation is also possible. When the computer receives the signal "tube end" from an inductive feeler in the tube transportation system, the results from the tube are evaluated. This evaluation is made when the connection plug is in the inspection chamber.

During the evaluation the number of values outside the tolerance limits are compared with a preset number. The two figures are printed and if one or both are above a preset number the tube will automatically be rejected. In our system the axial movement of the tube stops and the operator makes the decision. The inductive feeler actual sense the tube metal which differs from the plast connection plug, which means that the tubes neednot have the same length in order to be tested in our system.

# COMPUTER CONTROL IN MDT

TEST 1665							
-							
-							
2-							
-							
6-							
-							
7-							
91-							
TEST 1677 STOP							
TEST 1677							
CLASS NUMBER		1	2	3	4	5	7 8
		REJECTED		ACCEPTED		REJECTED	
OUTER DIAMETER							
SECTION A					169	1838	
SECTION B					684	11856	
WALL THICKNESS							
SECTION A				2	786	491	
SECTION B			38	6828	5682		
INNER DIAMETER							
SECTION A					18	1187	2
SECTION B					386	12189	49
TRANSVERSE DEFECTS		ACCEPTED		REJECTED			
SECTION A							
SECTION B							
LONGITUDINAL DEFECTS							
SECTION A							
SECTION B							

Fig. 5. Print out of an automatic test sequence of tube No. 1666 to 1677 and of tube No. 1677 with 5 parameters.

In fig. 5 the preset rejection criteria for dimensions and defects were 50 - 1. This means that the computer would reject the tube if more than 50 dimensional values and/or more than 1 defect value were outside the tolerance limits. The system accepted 11 tubes with no or a few dimension values outside the tolerance limits. Tube No. 1677 was rejected because 91 dimensions values were outside the tolerance limits. The printout disclose the actual parameters and shows the whole histogrammic distribution for all the parameters.

## IV. CALIBRATION

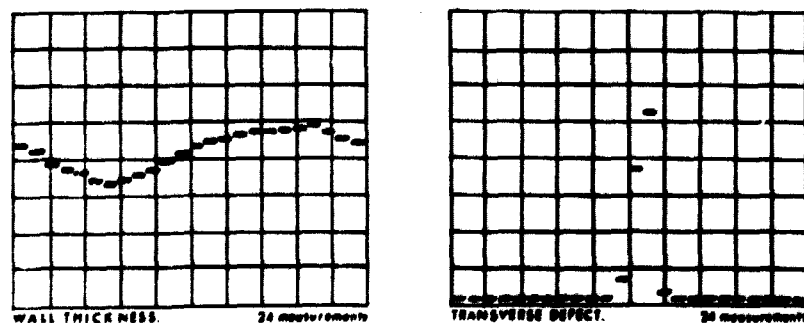


Fig. 6. Static calibration of the system at 3000 RPM.

## COMPUTER CONTROL IN NDT

The calibration of the inspection system is the basic for an accurate measurement. In our system we have the possibility to make a "static" calibration under dynamic conditions:

This is made by synchronizing the pulse repetition from the rotating water chamber. Thus with the chamber rotating 3000 rpm which is the actual testing speed and with no axial movement of the calibration tube, a fixed picture can be obtained on the oscilloscope.

The oscilloscope shows the signal variation around the tube for dimension measurement or defect inspection (Fig. 6).

For dimensions measurement this picture is now used for the correct setting of zero point and sensitivity when a tube with wellknown dimensions is in the system.

In defect inspection the corresponding picture is used to find the echo variation in a single quadrangle in the inspection set (Fig. 7). In practice this is performed by slowly turning the tube with the artificial reference defects and also moving it a little in the axial direction while the synchronized oscilloscope picture is observed. A storage oscilloscope is useful for this calibration.

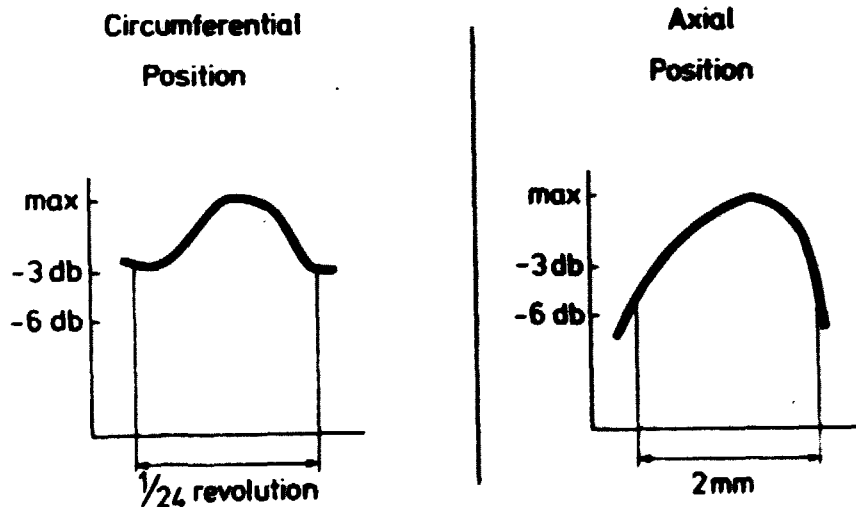


Fig. 7. Practical variation of the echo height within the "inspection quadrangle".

When the inspection quadrangle is chosen the minimum echo height from the reference defect can be determined. This value is used as a reject criteria in the automatic tube evaluation by the computer. All tubes with defects giving a higher echo will be rejected.

A second inspection of the rejected tubes with a smaller inspection quadrangle - more pulses per revolution, smaller pitch - may be carried out to confirm that, the rejection was correct. This may be performed for the whole tube or for the section of the tube where the defect was found.

The total output in such a two step inspection is much higher than in one inspection of all tubes with a small inspection mesh size, because most of the tubes would be accepted in the first inspection.



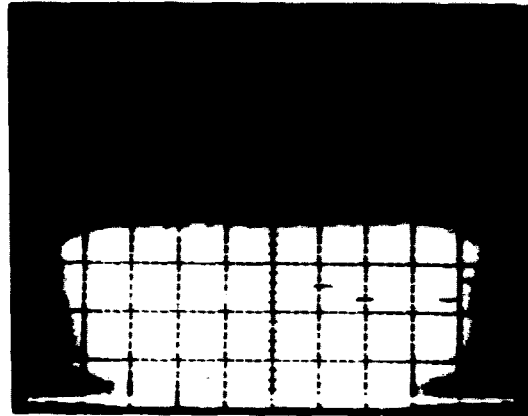


Fig. 8. Rotation symmetry of the inspection system.

If the tube with a reference defect in an optimal position is turned  $360^\circ$  without any axial movement, the rotational symmetry of the system can be disclosed on the storage oscilloscope (Fig. 8). In this picture it is possible to see if a defect is registered with the same optimal echo height regardless of its circumferential position.

#### V. COMPUTER CONTROL VERSUS NORMAL ANALOG RECORDING

The analog recording is well suited to get an overall impression of a single tube. In automatic inspection up to 1000 km of tube per year should be inspected at a single tube mill. This means up to 100 km of analog recording per year for a 100% inspection.

A correct evaluation of all these paper recording is not better than the human element because a visual examination of the records is the basis for acceptance or rejection.

Here the computer has the following advantages:

- Safety in the evaluation. The computer will not get tired or bored so all the results are judged with the same accuracy.
- The resolution could be higher around the tolerance limits. In our programme this would mean narrow classes around the tolerance limits.
- In defect examination one single indication will be registered. Hereby the inspection capacity may be enlarged as a greater inspection "mesh size" could be used. On the other hand, in analog recording each defect must be detected several times in order not to be overlooked in the evaluation. Therefore a higher capacity is obtained with computer control.
- Ovality and eccentricity in dimension measurement can be calculated.
- Acceptance/rejection criteria can be defined on every parameter and the computer can evaluate the results simultaneously with the test.
- The results can be stored for documentation and/or for further statistical analyses.  
(Trend analyses - mean values - rejection cause e.t.c.).
- The computer can handle the numbering of the tubes and the corresponding results.

## COMPUTER CONTROL IN NDT

### VI. CONCLUSION

The computer can be used in several ways in non destructive testing. The results we have obtained in practical tube testing both in the laboratory and in a canning tube factory are in compliance with the theoretical consideration. The computer does the fatiguing work of comparing many almost identical measurements with the specified tolerance limits.

However, the fundamental results from the inspection must of course be correct before the computer can make the correct judgement. Therefore we have established an accurate calibration procedure.

The analog recordings may sometimes be used to give a better judgement of a defect if this also shows up on the other defect channel and/or on the wall-thickness registration. The computer can be programmed to do this type of judgement with an increased safety. The reason for this is the extremely good tube guidance in our system and the fact that the defect inspection and dimensional measurements are made in the same system and in one pass of the tube.

If every transducer was fitted with its own micro processor all the measurements could be stored individually on tape and hence all the parameters for every part of the tube could be "analog" registered - with a suitable scale on the axis - when this tape is read by a large computer. Hereby the advantage of analog recording of a single tube could be maintained.

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